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STRAND MARKINGS IN THE PENNSYLVANIAN SANDSTONES OF OSAGE COUNTY, OKLAHOMA[1]

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INTRODUCTION
CONDITIONS OF SEDIMENTATION
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INTRODUCTION

While mapping geologic structure in Osage County, Oklahoma, the attention of the writer was called to certain grooves on bedding planes which resemble glacial striae and slickensides, although clearly of strand origin. They are but one of the many kinds of markings formed along shores or in shallow water. From parallel groovings over broad areas there are all gradations to irregular markings which are clearly casts of impressions in the mud. The markings appear both on upper and lower surfaces of sandstone beds, but they are more common on lower surfaces.

Similar markings in sandy beds of the Portage group of the Upper Devonian of Naples, New York, have been described in detail recently by Dr. John M. Clarke[2] and many years ago by Professor James Hall.[3] They have also been found in the Strawn formation of Pennsylvanian (Pottsville) age, both south of Strawn, Texas, and east of San Saba, in San Saba County, Texas.[4] Grooves of similar nature are known in the Beekmantown of Valcour Island, Lake Champlain.[5] No doubt they are much more common than these few localities indicate.

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[1] Published by permission of the director, United States Geological Survey.

[2] "Strand and Undertow Markings of Upper Devonian Time as Indications of the Prevailing Climate," *New York State Mus., Bull. 196* (1918), pp. 199–210.

[3] *Geology of the Fourth District of New York* (1843), pp. 234–37.

[4] The latter locality is known to Dr. J. A. Udden, of Austin, Texas.

[5] Personal communication from Dr. Rudolf Ruedemann, of Albany, New York.

The writer is indebted for information and suggestions regarding these markings to his former associates on the United States Geological Survey, Clarence S. Ross and Kenneth C. Heald. The best localities were found by R. H. Wood and D. D. Conduit of the Survey.

CONDITIONS OF SEDIMENTATION

During the middle and upper Pennsylvanian, when shales, sandstones, and limestones of the Osage were being deposited, a shallow sea with a continually oscillating shore line covered eastern Oklahoma and Kansas, and west-central Texas. The axis of the basin extended in a northeast-southwest direction with the southeastern shore line not far east of the eastern Osage and near the present outcrop of the Strawn formation in Texas.[1] The territory in Oklahoma in which the markings are found lies in the eastern Osage between Pawhuska, Hominy, Skiatook, and Tulsa. In this region limestones are thin and few, but highly fossiliferous. The sandstones commonly show ripple, current, and other strand markings; occasionally they are fossiliferous.[2] Stratigraphically the grooves are known in various horizons between the Hogshooter limestone and the Elgin sandstone, 1,000 feet apart. The Strawn formation in Texas is older than any of the Osage sediments.

DESCRIPTION OF MARKINGS

Nothing unusual has been noted in the current, ripple, and rill marks in the Osage sediments except that the current and rill markings appear in various stages of obscurity and some of the markings defy classification. They appear both on the upper and lower surfaces of sandstone layers. The nature of the parallel groovings may be judged by the photographs.

Localities in the Osage where markings may be seen are numerous. A few are given in the following list: (1) S.E. cor., N.E. ¼, Sec. 8, T. 20 N., R. 12 E., near F. A. Gillespie No. 1 (by R. H. Wood and the writer); (2) on a bald hill in W.½, Sec. 7, same township (by C. S. Ross); (3) N.W. cor., Sec. 6, same township, a V-shaped groove (by C. S. Ross); (4) Sec. 14, T. 24 N., R. 8 E. (by K. C. Heald); (5) N.W. ¼, S.W. ¼, Sec. 10, T. 25 N., R. 9 E. (by K. C. Heald, D. D. Conduit, and the writer); (6) Sec. 11, T. 21 N., R. 11 E. (by C. S. Ross, P. V. Roundy, and the writer); (7) in the stone wall surrounding the house of Tom Gilchrist and in the foundation of the house of A. P. Kennedy a mile northwest of the Tulsa Country Club, and in a stone house on Duluth Street south of the Country Club (by C. S. Ross and the writer).

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[1] Mr. A. W. McCoy, of Bartlesville, Oklahoma, has prepared extensive manuscript paleogeographic maps of these seas and has kindly given the writer the foregoing information and the correlation of the beds.

[2] "Structure and Oil and Gas Resources of the Osage Reservation, Oklahoma," *U.S. Geol. Survey, Bull. 686* (1919).

The Osage grooves occur on hard, massive sandstones ½ foot to 2 feet in thickness and are seen over broad surfaces or on slabs 1 foot to 5 feet in length. The only pronounced markings, like those illustrated, occur on under surfaces of blocks probably underlain by sandy shale. The grooved block at locality (6) above appears to be in place with rather poor ridges on the upper surface. Near Pawhuska (locality [5]) the markings are faint lines and fainter ridges not over ¼ inch in height seen in places on the upper surface of a bed exposed on the top of an unused quarry. They are subparallel and may be found for a distance of 70 feet measured across the ridges, but nowhere for a distance of more than 6 feet along the ridges.

The markings are rounded and smooth. They sometimes have vertical or even undercut sides and characteristically are covered with minute parallel lines on the sides of the larger ridges. Clearly defined V-shaped grooves are infrequent (Fig. 6). The width varies from that of a pencil line to 2 inches; it is uniform until the marking disappears. Neither depth nor height is, as a rule, more than ½ inch, but either may vary quite abruptly or be undulating in any single marking. Single straight markings with a relief of 2 to 3 inches are found alone and also associated with the other strand markings. Their origin apparently is similar to that of the parallel ones. Professor Hall (*op. cit.*) described one cast 6 inches in diameter. The relief of the surface shown in Figure 1, 5½ feet in length across the markings, is not more than 1 inch. No uniformity of spacing between the larger grooves in the cast has been observed. In some cases there are no coarse markings. Small ridges and large grooves in the cast seem to be the rule in one locality, but with the irregular and complicated markings, such as

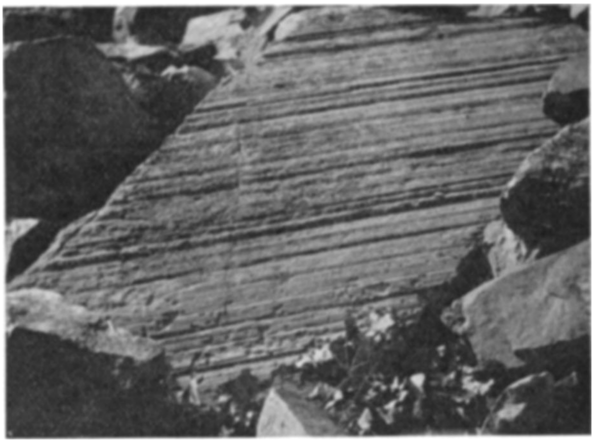

FIG. 1.—Block of sandstone 5½ feet in height showing parallel strand markings on a bedding plane. This is the lower surface of the bed and the markings are casts of the original. As shown by the ruler in one of the upper grooves, the coarser markings are grooves in this cast. The relief of the surface is less than 1 inch. Locality, S.E. cor., N.E. ¼, Sec. 8, T. 20 N., R. 12 E., Osage County, Oklahoma. Photo by Lucian Walker, of Tulsa, Oklahoma.

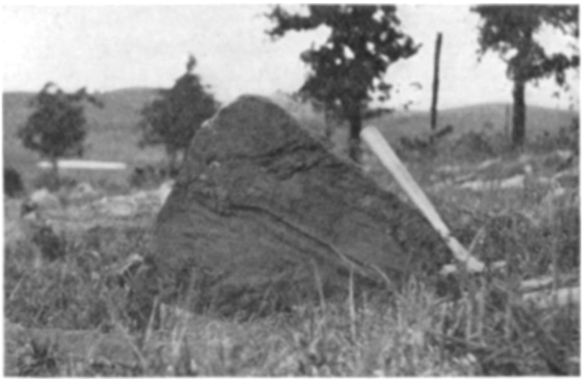

FIG. 2.—Another block of sandstone at the same locality as Figure 1, showing a curve in parallel markings, and also showing irregular markings which are depressions in the cast. Nothing but flexible objects such as fronds of algae could have produced a curve in some of the markings and not in others when dragged along the strand. The irregular markings near the top may be casts of stranded algae. Photo by R. H. Wood, United States Geological Survey.

Figure 5, the reverse is the case, and there are no depressions in the cast.

Parallelism is the striking characteristic of the markings: they are as straight and as parallel as if ruled with a straight-edge. Yet frequently the grooves end abruptly, but smoothly as seen in Figure 3, or the ridges and grooves in the cast may disappear one by one in a deep, curved, and narrow groove whose beginning is one of the grooves, but whose depth (a sharp ridge in the original) is fully $\frac{1}{2}$ inch. It is a sort of festoon, an arrangement very common in pahoehoe lava where the rumples in the lava are suddenly swept beneath the surface in a smooth curve. Sometimes some of the markings end in a rude curve or are curved along their length, the original direction being resumed beyond the curve (Fig. 2), while the other markings on the same slab are perfectly straight. Associated with some of the grooves are irregular small depressions and less abundant elevations in the cast (Fig. 2,

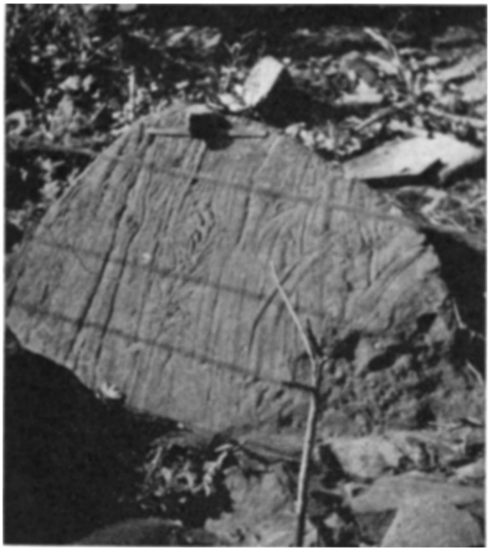

FIG. 3.—Irregular markings in another block of sandstone at the same locality as Figures 1 and 2. Suspended fronds of seaweed waving back and forth could produce these sinuous, intersecting fine grooves and ridges.

upper corner, Fig. 4). Cross-markings are infrequent in the well-striated surfaces, but common in the more irregular markings described below (Figs. 3, 6, 7). Professor Hall, however, figured one well-striated slab with three sets of parallel furrows.[1]

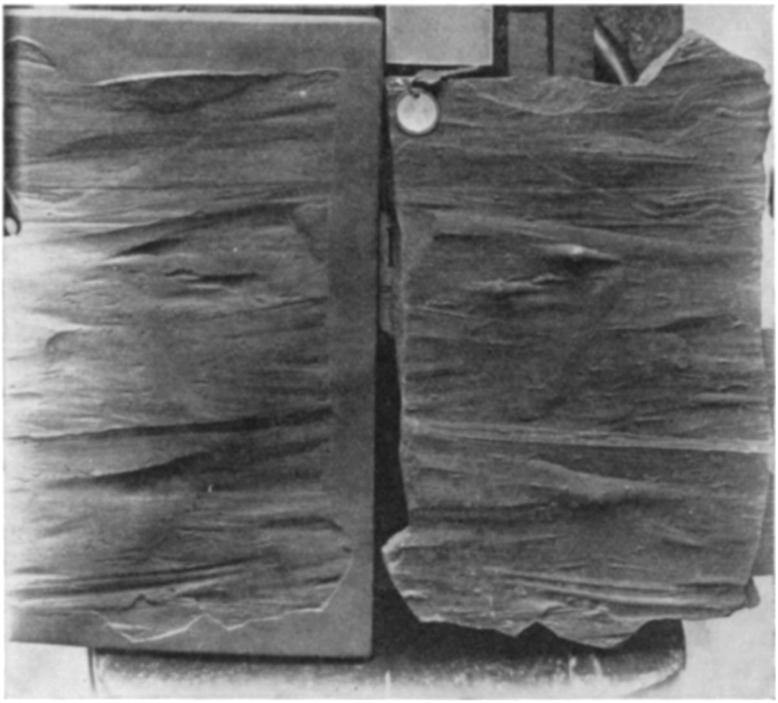

FIG. 4.—A slab of sandstone and a plaster cast of the same showing the original strand surface in the cast. The markings were depressions in the strands. Some of them represent very small dents made by objects swept along, but two of them strongly suggest nodal impressions of plants which, it is believed, lay on the strand. Locality, Naples, New York; Portage group of the Upper Devonian. Specimen in the New York State Museum.

Fossils are occasionally found in the grooves, but small rod-like impressions and gouges in the strand, as seen in Figure 4, are more common. Drifted shells fill grooves in the Beekmantown of Valcour Island, Lake Champlain, according to Dr. Ruedemann. Hall figures a slab showing on the original strand surface, two broad ridges separating a broad groove, the latter being filled with drifted shells which washed in after the surface was marked.

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[1] Reproduced by Clarke, *op. cit.*, p. 202.

Common strand markings have not been noted on the same slab with the most clearly defined grooves and ridges, but well-developed asymmetrical ripple marks, rill markings of various kinds, small irregular markings such as might represent worm tracks or burrows or algae have been found on sandstones either of the same bed or of beds higher or lower in the series. There are also smooth lumps which might have been lumps of sandy mud, faint single grooves or ridges, and faint symmetrical ripple marks with or without minute, superimposed, tubular lumps and worm tracks, the whole glazed with a thin film of iron oxide as are most of the markings.

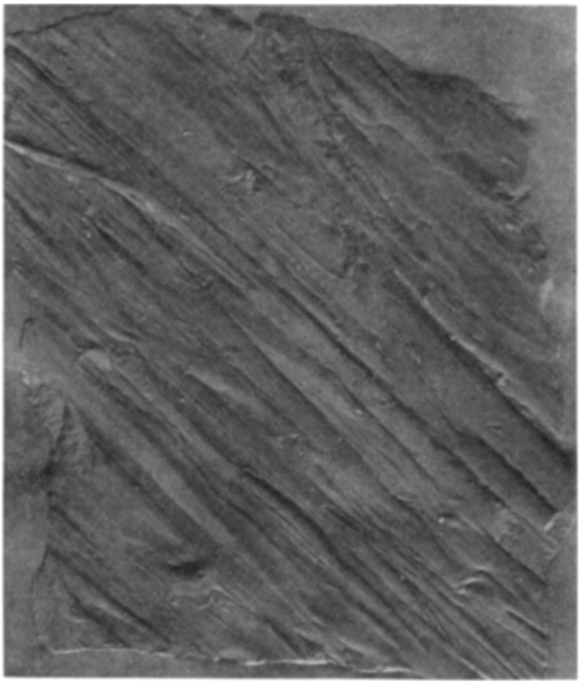

FIG. 5.—Casts of irregular markings, depressions in the strand, which appear to represent fronds of algae which lay on the beach. Near the right lower corner there is a piece of sandstone in the groove which in the original specimen looks suspiciously like the reverse side of a flattened stem of frond. Locality as in Figure 4.

Irregular markings, mostly grooves in the casts, are characteristic of many slabs of sandstone associated with the parallel markings. In Figure 3 they have the appearance of being made by objects swept back and forth on the strand while suspended from one or more common centers. Still more irregular markings (Fig. 5), all depressions on the strand, are composed of curved and crossed tubular casts, in cases more than an inch in diameter, and appear to represent casts of algae (or of something similar) which settled in the mud. From this state of irregularity it is but a step to nondescript markings the origin of which is probably inorganic.

Owing to the occurrence of most of the grooves on upturned blocks and to the fact that the beds underlying the casts have not been seen, it is not always possible to determine the original direction of the markings. In Sec. 11, T. 21 N., R. 11 E. it is N. 80° W.; in Sec. 10. T. 25 N., R. 9 E., N. 44°–52° W., which directions are down the depositional dip.

Plant remains have been found in one of the sandstone blocks associated with the grooved blocks in Sec. 8, T. 20 N., R. 12 E. and they occur in sandstone stratigraphically within a few feet of the grooves in Sec. 11, T. 21 N., R. 11 E. Casts of tree trunks have been found in abundance in the section 100 feet from the grooves in the former locality and the very fossiliferous Avant limestone is 80 feet from the grooves in the latter locality.

HYPOTHESES OF ORIGIN

Various hypotheses may be presented for the origin of the grooves: (1) impressions of plant remains, (2) dragging of parts of trees or roots, of algae or of pebbles over the strand, (3) action of ground ice molding unconsolidated sandy clays, (4) differential slipping of the beds before consolidation, (5) tidal action. These hypotheses will be examined in order.

1. *Impressions of plant remains.*—Trunks of trees or branches of algae impressed on the sandy mud could not have made the parallel striations such as are shown in Figure 1. They may well, however, account for some of the single markings, such as Figure 6. Definite worm trails are found on sandstones associated with the

grooved sandstones and casts of branching and interlacing stems generally admitted to represent algae are very common in the Osage rocks. Some of the slabs in the New York State Museum (Figs. 4, 5) show markings which, in the opinion of the writer, were formed as impressions of either algae, or of wood and nodes of plants. In some cases they show faint striations like the plant impressions of the same size on the Joggins section, Nova Scotia, or in the North Sydney section, Cape Breton Island (plates 18 and 22 of Clarke). In other cases the rounded elevations (filling of depressions in the original strand surface) may be partly broken from the rock (Fig. 5), showing that they had an upper as well as a lower surface and may represent casts of kelplike material. In the Tesnus formation of Pennsylvanian (Pottsville) age, 9 miles south of Marathon, Texas, and 225 feet below the top of the formation, there is a heavy sandstone bed showing mud flow and ripple marks and plant casts, but no groovings.

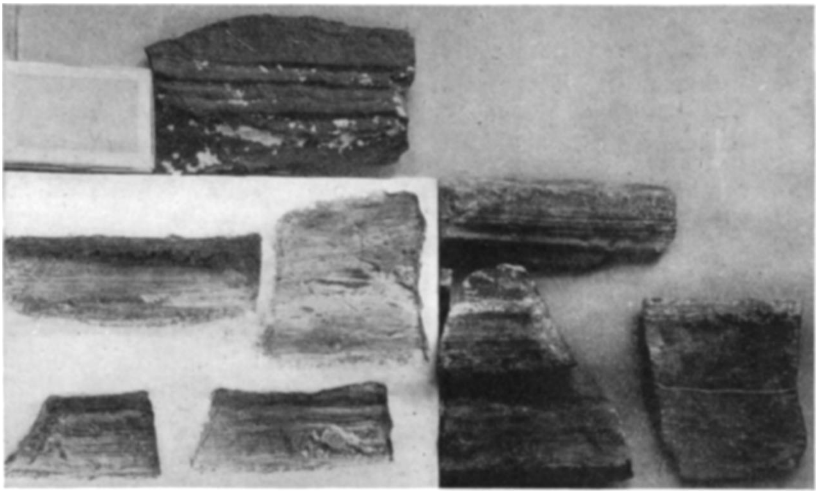

FIG. 6.—Blocks of sandstone in which are casts of V-shaped grooves and which are themselves grooved with sinuous lines. The plaster cast at the left shows the original. A branch or root dragged over fine-grained argillaceous sand could produce such grooves. Locality, Strawn, Texas. The block of sandstone at the top shows somewhat comparable markings produced by weathering of cross-bedding. Locality, basal Eocene, southeast of Uvalde, Texas.

Short, rodlike markings of obscure origin, so-called *Fucoides graphica*, recently have been ascribed to ice crystals by Dr. Clarke at the suggestion of Professor Woodworth.[1] Dr. Udden has enlarged on the suggestion by redescribing similar markings in the Cretaceous of Texas and of the Black Hills as fossil ice crystals.[2] The markings resemble the shorter ones on Figure 4. They are either straight or curved; they are 1 inch to 2 inches in length and $\frac{3}{16}$ to $\frac{1}{4}$ inch in diameter. The same markings are common in the Osage, and in the continuation of the same sandstones near Henryetta, Oklahoma. Faint markings of the same shape occur in the same horizon as some of the grooves. Measured ice crystals have not exactly the same shape as most of the supposed fossil crystals, but the branching and radiating forms are similar. The specimens in the New York State Museum show that the supposed crystals represent casts of crystals or of objects partly buried in the mud, because the ridges in the cast where they join or cross are distinctly superimposed, and in one case the newer object has bent down the older one. Ice crystals could scarcely bend one another, nor could they be depressed by any objects moving over or resting on them. Worm tubes, as

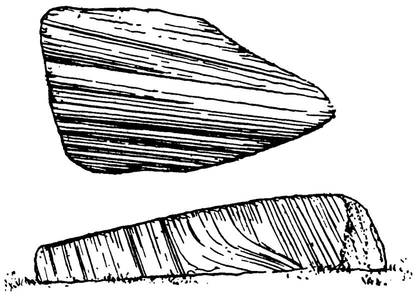

FIG. 7.—Casts of diverging grooves on the lower surfaces of sandstone blocks. The upper figure shows a slab 4 feet long in stone wall near Tulsa Country Club, Tulsa, Oklahoma; the lower figure shows a slab 5 feet long at the same locality as Figure 1.

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[1] J. M. Clarke, *op. cit.*, p. 205; J. B. Woodworth, *et al.*, "The Glacial Brick Clays of Rhode Island and Southeastern Massachusetts," *17th Ann. Rept., U.S. Geol. Survey* (1896), Part 1, p. 992; T. M'K. Hughes, "On Some Tracks of Terrestrial and Fresh Water Animals," *Quar. Jour. Geol. Soc.*, London, Vol. XL, No. 157 (1884), p. 184; J. E. Talmage, "Notes Concerning Certain Linear Marks in a Sedimentary Rock" (Abstract), *Quar. Jour. Geol. Soc.*, London, Vol. LII (1896), p. 461; *Univ. Utah Quarterly* (December, 1895).

[2] J. A. Udden, "Fossil Ice Crystals," *Univ. of Texas Bull.* (*1821*), (1918); *Sci. Amer.*, Vol. LXXII (1895), p. 102; "A Sketch of the Geology of the Chisos Country, Brewster County, Texas," *Univ. of Texas, Bull. 93* (*Science Series No. 11*) (1907), p. 32; D. D. Christner and O. C. Wheeler, "The Geology of Terrell County, Texas," *Univ. of Texas Bull.* (1918), p. 15.

beautifully exhibited in slabs forming pillars at the south entrance to the Tulsa Country Club (Tulsa, Oklahoma) characteristically are superimposed, and have the same diameter as the supposed crystal tubes. It is barely possible that climatic conditions in the several geologic periods in which these markings were formed were such that ground ice and ice crystals could form.

2. *Dragging of parts of trees or roots of algae or of pebbles over the strand.*—Groovings in sandy clay may be produced by shoving or dragging objects over the surface either above or below water. The alga, *Ulva enteromorpha*, has been observed dragging pebbles over the strand making depressions.[1] Ulva grows in tufts 6 to 8 inches high attached to one side of pebbles as large as $\frac{3}{4}$ inch in diameter. The fronds stand upright from the anchoring pebble, and wave back and forth dragging the pebble, but not lifting it. Either single or double grooves are produced, and the grooves in the illustrations cannot be distinguished from many of the single Osage grooves. One can readily imagine how this operation could produce many of the irregular Osage markings, especially those which cross (Fig. 3), but pebbles are very rare in the Osage sediments.[2] To produce parallel groovings bunches of large algae could be washed along by the tide, and where the algae came to rest irregular depressions would be produced in the sandy shale as stated above. Curves in the grooves, especially in some and not in others, could readily be produced by obstructions in the path of the algae (Fig. 2, upper corner) or by swirls in the tidal action, or by undertow.

Fragments of fossil wood indicate the presence of trees at the same horizon as the parallel markings. Were a log washed over the strand it would normally rotate; were a stump dragged along some of the roots would make deep, sharp-pointed grooves and ridges such as are occasionally found alone (Fig. 6). A log could not make the curved and diverging markings, but light pieces of wood could produce superimposed series of striations. Single grooves with finely striated sides unassociated with other strand markings have the appearance of being made by roots or other portions of trees.

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[1] A. P. Brown, "The Formation of Ripple Marks, Tracks, and Trails," *Proc. Acad. Nat. Sci.*, Philadelphia, Vol. LXIII (1911), pp. 536–47.

[2] C. S. Ross reports a conglomeratic limestone in the south part of T. 22 N., R. 7 E., that contains gravels and small pebbles of white vein quartz, igneous, and metamorphic rocks which were possibly carried by floating ice.

3. *Action of ground ice molding unconsolidated sandy clays.*—Floating land ice has been shown by Lyell to be capable of furrowing consolidated sandstone.[1] Dr. Clarke and Professor Woodworth concur in the opinion that the markings in the Upper Devonian of New York are of similar origin. The occurrence described by Lyell was at Cape Blomidon, on the Bay of Fundy, where heavily "packed" ice often 15 feet thick with fragments of amygdaloidal basalt frozen in the base, is pushed over ledges of Triassic sandstone with the rise of the tide.

Climatic conditions such that land and ground ice could be formed at various times during the deposition of 1,000 feet or more of sediments in the middle and upper Pennsylvanian are within the range of possibility and the faunas and floras would not necessarily prove or disprove such an assumption.[2] But if floating ice were present it should have gouged out the muds in some places and produced considerable lumps in others. Contrast the absence of such disturbances with Dr. Kindle's description of the action of "ice-shoved bowlder or ice cake" in the Mackenzie River:

> The plowing and gouging action of ice is nearly everywhere in evidence along the Mackenzie. At the head of the river, in the eastern shallow channel, one can see through the clear water numerous deep grooves made by ice cakes or bowlders pushed by ice in the bowlder clay of the bottom. In the gravel or slits of low islands the broad grooves made by ice-shoved bowlders or ice blocks can often be traced for a considerable distance. In some localities the plowing and scooping action of the ice carries quantities of mud from the bottom to the banks of the river.[3]

A comparatively smooth surface on the bottom of the ice would produce the required parallel markings and might produce cross-markings, but not the irregular markings unless small cakes of ice floated or were dragged around. Some of the irregularities (largely sharp ridges and elevations in the original) might have been formed by the melting of ice around mud-filled cracks. There was no regional Pennsylvanian glaciation in the Osage, for tillites have not been found. Bowlders of large size which have been interpreted as indicating the presence of floating ice during the early Pennsylvanian (Pottsville) in the vicinity of the Arbuckle and Ouachita mountains has caused considerable discussion.[1] Recently Professor Samuel Weidman has found striated pebbles in the Franks conglomerate of the Arbuckle Mountains together with the striated floor of older rocks on which the conglomerate rests.[2] This conglomerate is much older than the sediments of the Osage. Another reported locality of tillite near Shafter, Presidio County, Texas, has been examined by the writer and is believed by him not to be tillite.[3]

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[1] *Travels in North America*, Vol. II (1845), p. 144.

[2] "It seems possible to state that there is evidence for presuming that the Permian glacial period was preceded in the Carboniferous by a degree of cold permitting floating ice in continental bodies of water and also in the sea in middle latitudes."—J. B. Woodworth, "Boulder Beds of the Caney Shales at Talahina, Oklahoma," *Bull. Geol. Soc. Amer.*, Vol. XXIII (1912), pp. 457–62; quotation p. 462.

[3] "Notes on Sedimentation in the Mackenzie River Basin," *Jour. Geol.*, Vol. XXVI (1918), pp. 341–60; quotation p. 353.

Opposed to the theory of floating ice is the fact that nowhere are any of the striated sandstone beds gouged or beveled obliquely to the bedding planes; nor are the latter in any way disturbed. The varied and complex strand markings, which are much more abundant than the grooves on the various blocks of sandstone at the same locality, have never been rubbed by ice.

4. *Differential slipping of beds before consolidation.*—Slipping in unconsolidated beds, especially in muds and silts, is a well-known phenomenon recently emphasized in the mud lumps of the Mississippi delta[4] and in experiments by Dr. Kindle.[5] The latter

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[1] J. A. Taff, "Ice-borne Boulder Deposits in Mid-Carboniferous Marine Shales," *Bull. Geol. Soc. Amer.*, Vol. XX (1909), pp. 701–2; *Science* (New Series, Vol. XXI (1905), p. 225; E. O. Ulrich, "Revision of the Paleozoic Systems," *Bull. Geol. Soc. Amer.*, Vol. XXII (1911), p. 352, footnote; J. B. Woodworth, *op. cit.*

[2] "The Probability of Pennsylvanian Glaciation of the Arbuckle Mountain Region," *Bull. Geol. Soc. Amer.*, Vol. XXXII (1921).

[3] J. A. Udden, "The Geology of the Shafter Silver Mine District, Presidio County, Texas," *Univ. of Texas Mineral Survey, Bull. 8* (1904), pp. 14, 59. The only conglomerates found by the writer are at the base of the Cieneguita series as determined by the intrusive contact with syenite porphyry. They are very fine conglomerates and sandstones composed of rounded quartz pebbles and grains which look like fragments of vein quartz rounded by long water erosion.

[4] E. W. Shaw, "The Mud Lumps at the Mouths of the Mississippi," *U.S. Geol. Survey, Prof. Paper 85b* (1914), pp. 11–27.

[5] E. M. Kindle, "Deformation of Unconsolidated Beds in Nova Scotia and Southern Ontario," *Bull. Geol. Soc. Amer.*, Vol. XXVIII (1917), pp. 323–34.

has shown that when soft beds are overlain by unequally disturbed heavier and firmer beds there is a marked deformation of the former caused by differential weighing of the firmer upper beds. In the Osage the overlying heavy sandstones are equally distributed over large areas, but were the strands inclined, slipping could conceivably take place in sediments of the right composition producing modified slickensides on the bedding planes.[1] Again, were there readjustments within the subsiding geosynclinal basin during deposition, such as faulting, which Mr. A. W. McCoy tells the writer took place in the Osage basin, slipping would be expected along bedding planes, just as slipping is known to have been caused by earthquakes.

Difficulties not overcome by a slipping hypothesis, even assuming that sandy clays and sandstones would slide, are the explanations of systems of cross-markings, and the absence of buckling of the strata or of intraformational conglomerate. Slickensiding after consolidation is not a possibility because the markings are clearly molded, not gouged.

5. *Tidal action.*—Current and tidal action produce a variety of markings on the strand, a number of which have been figured by Dr. Clarke and which can be reproduced in the Osage sandstone and in the Tesnus formation sandstone of the Marathon region, Texas; especially the "mud flows" which are interpreted as plunge and undertow markings of retreating waves on the beach. The larger ones, which are 2 to 5 inches in width and 1 inch in depth may have been formed, as suggested to the writer by Mr. C. A. Hartnagel, of the New York State Museum, in tiny puddles of water on a gently sloping beach swirled by sudden gusts of wind. Professor Hall's theory of the origin of the parallel markings is by current action:

> The only assignable cause for these ridges is the action of a current flowing over the surface of the strata, sometimes transporting sand and at other times coarser material which furrowed the surface upon which the subsequent deposits were made.[2]

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[1] Dr. J. A. Udden has kindly called the attention of the writer to photographs of sandstone slabs showing minute faults and wavy subparallel folds, the origin of which he believes to have been creep of settling muds before consolidation, but these folds do not resemble the strand markings (*Univ. of Texas, Bull. 246* (1912, Pl. 25).

[2] *Op. cit.*, pp. 234–35.

Cross-bedded sandstones may show very similar grooves and ridges when relief is accentuated by weathering (Fig. 6), but the two kinds of markings are entirely distinct in origin.

CONCLUSIONS

Parallel groovings on bedding planes such as described above have been shown to be markings on the original strand either in sandy clay or in a fine-grained sandstone. Preservation of either the original surface, as in the case of the sandstones, or of a cast of the surface, as in the case of the sandy clays, has failed to reveal both original and cast of any one set of markings except in the form of small fragments.

Inspection of the various theories which may be advanced to account for the formation of such strand markings shows that they have been formed by the dragging of plants, probably stems and fronds of algae, over sand and mud in shallow water, probably by tidal or undertow currents. Ground ice and shore ice are shown to be incapable of having made these markings.

Reasons for the conclusions above may be briefly summarized: (1) general distribution through formations of similar origin, but of different ages in various regions; (2) perfect parallelism over broad surfaces with notable undulations and sinuosities confined to certain of the markings; (3) curved, overlapping, and cross-striations; (4) absence of any disturbance within the strata; (5) intimate association with beach and shallow water markings as current, ripple, rill marks, worm borings, and algal impressions; (6) occasional association with heaps of shells found in the grooves and stratigraphic proximity of plant remains; (7) negative evidence of the presence of ice in any form or of glacial deposits in the containing formations; (8) complete gradation from straightness to curvature to cross-markings and more irregular markings showing nodal and stemlike impressions; and (9) the outstanding delicacy of the whole, showing that gouging was subordinate to molding by objects of light weight.